Indonesian Journal of Electrical Engineering and Computer Science
Vol. 12, No. 1, October 2018, pp. 30~37
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v12.i1.pp30-37

Direction of Arrival Using Uniform Circular Array Based on 2-D MUSIC Algorithm

Mohammed Amine Ihedrane[1], Seddik Bri[2]
[1]Materials and Instrumentations group, High School of Technology ESTM, Moulay Ismail University, Meknes, Morocco
[2]Spectrometry Laboratory of Materials and Archaeomaterials, Faculty of Science, Moulay Ismail University, Meknes, Morocco

Article Info

Article history:

Received Jan 12, 2018
Revised Apr 21, 2018
Accepted May 27, 2018

Keywords:

Direction of arrival
Multiple signal classification
Uniform circular array
Uniform linear array

ABSTRACT

This study presents the conception, simulation, realisation and characterisation of a patch antenna for Wi-Fi. The antenna is designed at the frequency of 2.45 GHz; the dielectric substrate used is FR4_epoxy which has a dielectric permittivity of 4.4.this patch antenna is used to estimate the direction of arrival (DOA) using 2-D Multiple Signal Classification (2-D MUSIC) the case of the proposed uniform circular arrays (UCA). The comparison between Uniform circular arrays and Uniform Linear arrays (ULA) demonstrate that the proposed structure give better angles resolutions compared to ULAs.

Corresponding Author:

Mohammed Amine Ihedrane,
Department of Materials and Instrumentations group,
High School of Technology ESTM, Moulay Ismail University,
Meknes, Morocco.
Email: amine.ihedrane@gmail.com

1. INTRODUCTION

Smart antenna technology includes AOA estimation and Beam forming. There are a lot of Angle of Arrival (AOA) estimation algorithms, which are divided in to two different types: maximum likelihood DOA estimation algorithm and subspace based DOA estimation algorithm. The maximum likelihood DOA estimation algorithm is such as ML estimation algorithm [1]. The representative subspace based DOA estimation algorithms are MUSIC algorithm [2], ESPRIT algorithm [3], and WSF algorithm [4]. There are various methods to estimate the angle of arrival (DOA) of radio signals on the antenna array.

DOA estimation techniques can be broadly divided into three different categories namely; conventional methods subspace based methods and maximum likelihood methods. Convolution methods are based on the concepts of beam forming and null steering, but it requires a large number of elements to provide high resolution. Examples of this method are delay and sum and Capon’s minimum variance method [5]. One major limitation of this method is poor resolution that is its ability to separate closely spaced signals. Unlike conventional methods, subspace methods exploit the information of the received data resulting in high resolution. Two main subspace based algorithms are Multiple Signal Classification and Estimation of Signal Parameters via Rotational Invariance Techniques [6].

The DOA algorithms are classified as quadratic (non- subspace) type and subspace type. The Bartlett and Capon (Minimum Variance Distortion less Response) are quadratic type algorithms. Both methods are highly dependent on physical size of array aperture, which results in poor resolution and accuracy. Subspace based DOA estimation method is based on the Eigen decomposition. The subspace

based DOA estimation algorithms MUSIC and ESPRIT provide high resolution; they are more accurate and not limited to physical size of array aperture [7-8].

These algorithms give information about number of incident signals and DOA of each signal. Maximum likelihood method is one of the first techniques to be investigated for DOA estimation but has the drawback of intensive computational complexity [9]. Deployed at the base station of the existing wireless infrastructure, smart antennas are capable of bringing outstanding capacity improvement (very important in urban and densely populated areas) to the frequency-resource-limited radio-communication system by an efficient frequency reuse scheme. This unique feature has been made feasible through the impressive advances in the field of digital signal processing, which enable smart antennas to dynamically tune out interference while focusing on the intended user. DOA estimation technology is focused on high resolution estimation algorithm. In multiple DOA estimation algorithms, a promising method for smart antenna array is MUSIC algorithm [10].

It has been proven both theoretically and experimentally that smart antennas can provide the benefits stated above, but possibly the most challenging problem related to adaptive antennas is their practical implementation [6]. Digital signal processing (DSP) algorithms related smart antennas come at a high computational expense making their real time implementation difficult. Until now, the investigation of smart antennas suitable for wireless communication systems has involved primarily uniform linear arrays (ULA). Different algorithms have been proposed for the estimation of the direction of arrivals (DOAs) of signals arriving to the array and several adaptive techniques have been examined for the shaping of the radiation pattern under different constraints imposed by the wireless environment [11], [12]. Albagory et al. proposed an array structure for fast and computationally efficient 2D-DOA estimation using the MUSIC algorithm. This technique separates the noise and the signal subspace based on eigenvalue decomposition of the spatial covariance matrix, the conventional signal processing algorithms [13].

This paper is organized as follow: The definition and the proposed Music algorithm are presented in section 2 and 3 Then realized patch antenna geometry is designed in section 4. Their simulation results and the comparison between the MUSIC method and the experimented ones are compared in section 5, followed by the conclusion.

2. MODEL OF SIGNALS AND 2D-MUSIC ALGORITHM

MUSIC means Multiple Signal Classification [14], is a high resolution DOA estimation algorithm. It gives the estimate of DOA of signals as well as the estimate of the number of signals [15]. In this algorithm, the estimation of DOA can be carried out by using one of the subspaces either noise or signal. The capacity of DOA estimation using UCA-MUSIC shows in Figure 1 is bounded by the number of antenna elements. These techniques need to estimate the DOAs of all target signals and interference, which decreases the accuracy of the DOA estimation [16-17]. We assume that there are N uniform circular array, M narrow band far field signals from different incident direction. The radius of the circular array is denoted as r and wavelength of narrow band is denoted as λ.

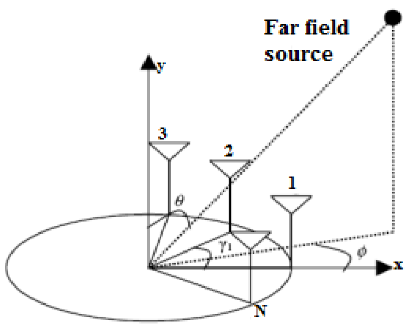

Figure 1. Uniform Circular Array (UCA) with N elements

Choose a signal source S (t) impinges on the array with an angle θ. If the received signal at the first element is x1(t) = s(t), then the delay at element i is:

$$\Delta i \;= \frac{(i-1) d \sin\theta}{c} \tag{1}$$

If there are M sources the signals received at the array the received signal vector is given by:

$$X = AS(t) + N(t) \tag{2}$$

Where A=[a $(\theta_{1,}\varphi_1)$,…,a $(\theta_{2,}\varphi_2)$] is a (N×M) matrix of the M steering vectors and S=[S1(t),…,SM(t)]T is a signal source vector of order (M×N). $[\ ]^T$ denote transpose of a matrix and N(t) is N(t) = [n1(t), n2(t), ..., nN(t)]T is the tth snapshot of either zero mean stationary complex additive white gaussian noise (AWGN). The correlation matrix of received vector can be written as:

$$R \;= E[XX^H] = \; E[ASS^H A^H] + E[WW^H] \;= \; AVA^H + \sigma^2 I \tag{3}$$

Where σ^2 is the variance of white Gaussian noise vector (W), V is covariance matrix of signal vector (S) which is a full rank matrix of order (M×M) given by:

$$V = E[SS^H] \\ = \begin{bmatrix} E[|S_1|^2] & \cdots & \ldots & 0 \\ 0 & E[|S_2|^2] & \ldots & 0 \\ \vdots & \ddots & \ldots & \vdots \\ 0 & 0 & \ldots & E[|S_M|^2] \end{bmatrix} \tag{4}$$

Where the statistical expectation is denoted by E [ ], Rs is a signal covariance matrix of order (N×N) with rank M given by:

$$Rs = \begin{bmatrix} E[|S_1|^2] & \cdots & \ldots & 0 & \ldots & 0 \\ 0 & E[|S_2|^2] & \ldots & 0 & \ldots & 0 \\ \vdots & \ddots & \ldots & \vdots & .. & 0 \\ 0 & 0 & \ldots & E[|S_M|^2] & .. & 0 \\ 0 & 0 & \ldots & 0 & \ldots & 0 \end{bmatrix} \tag{5}$$

R_S, has (N-M) Eigenvectors corresponding to zero eigen values. We know that steering vector $a(\theta_{1,}\varphi_1)$ which is in the signal subspace is orthogonal to noise subspace let $Q_n$be such an eigenvector.

$$R_S\, Q_n = AVA^H Q_n = 0 \tag{6}$$

Since V is a positive definite matrix:

$$a^H(\theta_i, \varphi_i) Q_n = 0 \tag{7}$$

This implies that signal steering vectors are orthogonal to eigenvector corresponding to noise subspace [9-11]. So the MUSIC algorithm searches through all angles and plots the spatial spectrum:

$$P_{MUSIC}(\theta, \varphi) = \frac{1}{(a^H(\theta,\varphi) Q_n Q_n{}^H a(\theta,\varphi))} \tag{8}$$

3. PROPOSED METHOD

In the proposed algorithm, we will reconstruct the signal matrix,

$$H{=}E\, X^* \tag{9}$$

Where ‘*’ represents complex conjugate, E is an N order inverse identity matrix which is called transition matrix. The covariance matrix of the data H is:

$$R_Y \;= E\, R_X{}^*\, E$$

We introduce a new array covariance matrix, which is the sum of RY and Rx

$$R = R_Y + R_X = AR_{sA} + E[AR_sA]^* E + 2\sigma^2 I$$

According to the proposed matrix theory, if q is an eigenvector corresponding to a zero eigen value of matrix ARSA, then q must also be an eigenvector correspond to the zero eigen value of matrix E [ARSA]*E. We observe that matrix Rx, RY and R have the same noise subspace. By performing eigen value decomposition with R, we get its eigen values and its eigen vectors. So to the estimated number of signal sources, the noise subspace among the eigen vectors can be proved. With the new noise subspace, we can construct MUSIC spatial spectrum.

4. ANTENNA DESIGN

A smart antenna system is a system aided by some smart algorithm designed to adapt to different signal environments. Smart antenna is an antenna system that can modify its beam pattern or other parameters, by means of internal feedback control while the antenna system is operating. The basic idea behind s mart antennas is that multiple antennas processed simultaneously allow static or dynamical spatial processing with fixed antenna topology [19]-[20]. The pattern of the antenna in its totality is now depending partly on its geometry but even more on the processing of the signals of the antennas individually. Several algorithms have been developed based on different criteria to compute the complex weights [21-22].

For a better impedance matching, a simple rectangular sequence is proposed on the realized patch antenna presented in Figure 2. The parasitic element is introduced in order to increase the effective surface area of the proposed antenna. In this design, the FR4 epoxy substrate is used. The substrate height is 1.6 mm, the dielectric constant is 4.4 and the loss tangent is 0.02. The patch antenna is fed by an axial microstrip line.

$$P_{MUSIC}(\theta, \varphi) = \frac{1}{\left(A(\theta,\varphi)^H q_n q_n{}^H A(\theta,\varphi)\right)} \quad (12)$$

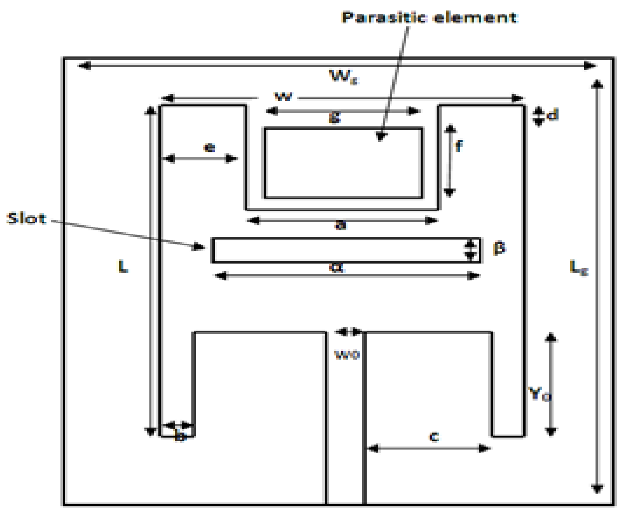

Figure 2. Proposed patch antenna

The dimensions for the proposed patch-H antenna resonate in frequency f0 = 2.45GHz, are given in the Table 1. In this design, the FR4 epoxy substrate is used. The height h of the substrate is 1.6 mm, the dielectric constant εr is 4.4 and the loss tangent is 0.02. The patch antenna is fed by an axial microstrip line.

Figure 3 present an antenna resonate frequency at 2.45GHz for the experimental and simulated for proposed patch with return loss between -40dB and -36dB. So we can say that proposed antenna exploit well Wi-Fi. The parasitic element is introduced to increase the effective area of the proposed antenna.

Table 1. Properties of proposed antenna

Parameters	values
Wg	46
Lg	51
L	34
W	20
Ereff	5.92
ΔL	0.4722

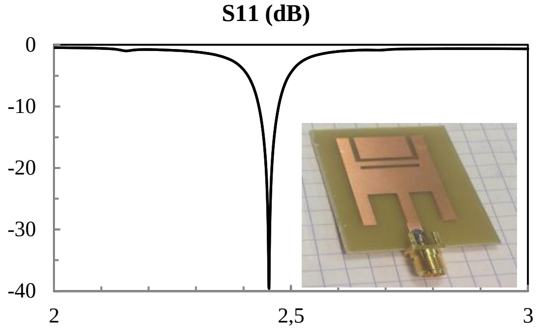

Figure 3. Experimental returns loss of proposed patch

5. RESULTS AND ANALYSIS

5.1. Simulated results for the proposed antenna geometry

Figure 4 present the proposed structure for the uniform circular array studied in this work using HFSS. The software enables to compute antenna array radiation patterns and antenna parameters. HFSS models the array radiation pattern by applying an “array factor” to the single elements pattern [20]. The radius of circular array is chosen to get an inter-element distance of 0.5λ. Figures 5-6 shows that after determined angles by using 2–D MUSIC method, proposed geometry directs the main beam towards the user and at the same time forms nulls in the directions of interferers in the case of two and tree signals. From Figure 6 we observe that 2–D MUSIC method using the proposed geometry can be applied for correlated sources to eliminate multipath (when the antenna receives the desired signal and its various multipath components).

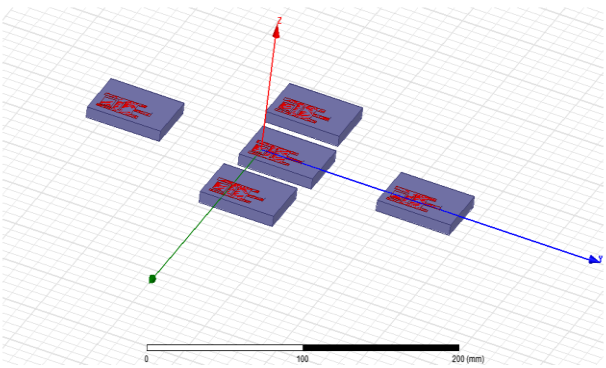

Figure 4. (4+1) proposed patch antenna structure

5.2. Comparative results between proposed UCA and ULA geometry Using MUSIC Algorithms

In order to demonstrate the direction of arrival of the spectral technique using the results of proposed experimental patch antenna indicate above. We have been compared the results with an experimented ones [23-25] for different cases to: a uniform circle array (UCA) with five antennas, radius r=124 mm. The radiation source is pulse signal and the distance between the radiating antenna and the direction finder receiving antenna approximately is 8 m. The carrier frequency is 6 GHz and the SNR is

20 dB according to [23] shows in Figure 7. 4x4 planar antenna array with0.5λ element spacing for [25] illustrate in Figure 8 and UCA with 8 antenna element, 2 source and noise = 12 dB, with BPSK, 2ASK modulation mode, the search step of MUSIC is 0.1° and the noise intensity is -12 dB according to [25].

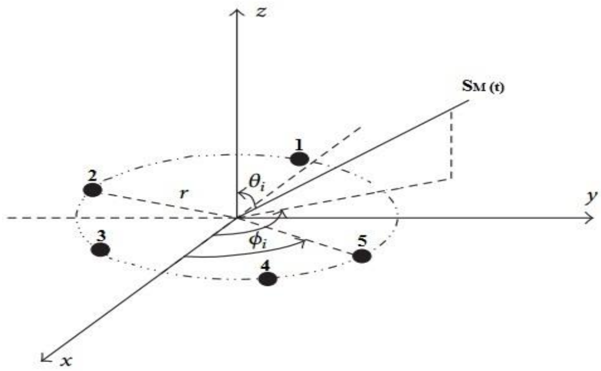

Figure 7. Uniform Circular Array (UCA) with 5 elements

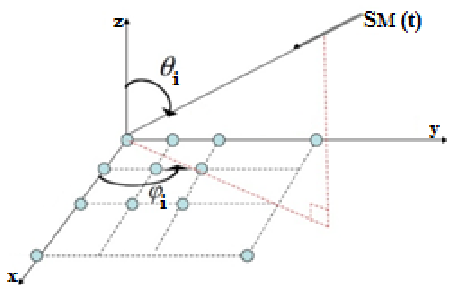

Figure 8. (4x4) planer antenna with 0.5 λ

To compare the proposed algorithm MUSIC with an experimented one [23], a first simulation under the same condition was made as shows in Figue 9 we employed two unequal power signals arriving at azimuth and elevation (133.6°,137.8°) and (78.6°, 82.4°), respectively. One signal power is 7dBm and the other one is 5dBm. Now we depict the spectrum of the MUSIC and the this work with receiving data, we note the method in this work can resolve clearly the azimuth elevation (132.4°, 136.2°) and (78°, 84°) and the peaks are sharp, while the Music [23] whose estimations (130°, 138.5°) and (79°, 82.5°) are far from(133.6°,137.8°) and (78.6°, 82.4°) , the peaks are less sharp.

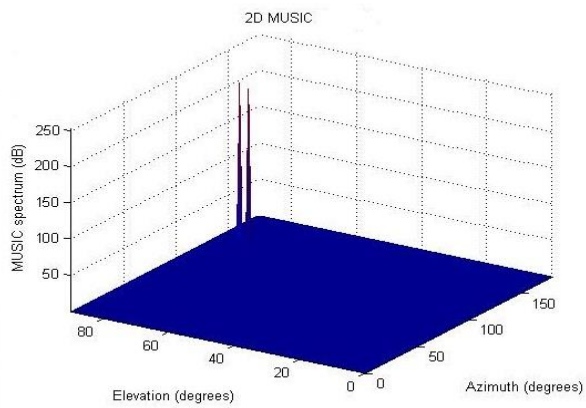

Figure 9. Simulation for azimuth and elevation (133.6, 137.8) and (78.6, 82.4)

A second simulation was made by changing the azimuth and elevation, (128.4°,116°) and (78°,84°), respectively and keeping signals power in 7dBm and 5dBm. It is observed from Figure 10 each algorithm could separate the two signals, while comparing with the peak of the MUSIC algorithm [24], and the proposed algorithm's is much sharper. Furthermore, the DOA estimations of the new method are (128.4°,115.3°) and (78°,84°), which is more accuracy than MUSIC method whose estimations are(129.5°,117°) and (78.5°,82.5°).

Figure 11 shows that angles have the same values but the developed method present a good Magnitude for angles (99.48 50.13); (64.88 15.1) the magnitude is 40.15 dB, 38.84dB respectively. Results indicate that this work gives a higher value of peaks and estimates successfully the angles with an efficient magnitude: +0.24 % for angles (99.48; 50.13) and +0.02 % for angles (64.88 15.1) compared to the proposed one [25].

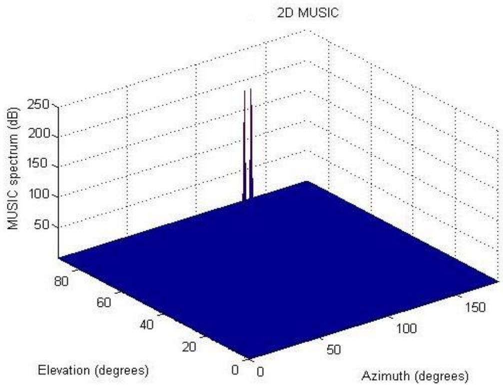

Figure 10. Simulation for azimuth and elevation (128.4, 116) and (78, 84)

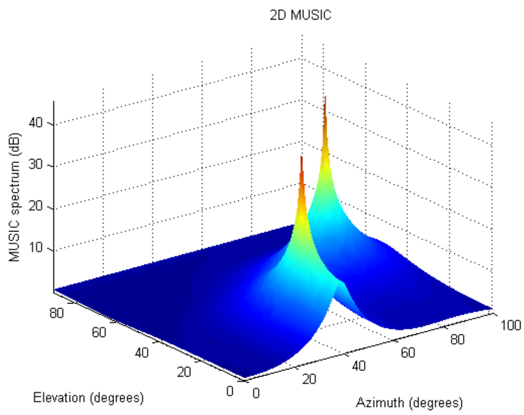

Figure 11. Simulation for azimuth and elevation (99.48, 50.13) and (64.88, 15.1)

We conclude that the proposed UCA geometry can obtain directly the main beam towards the user and at the same time forms nulls in the directions of interferers in the case of two and tree signals and we can observe that 2–D MUSIC method using the reconfigurable geometry can be applied for correlated sources to eliminate multipath (when the reconfigurable receives the desired signal and its various multipath components).

6. CONCLUSION

This article presents the results of direction of arrival estimation using 2-D MUSIC. The proposed algorithm takes full advantage of proposed geometrical norm of UCA. We recommend MUSIC based on UCA for estimation of DOA system for the following reasons: it is easier to arrange the circular

array on an aircraft or a satellite, the signals with the same frequency are independent for aerial reflectors around the antenna, and this avoids the defect of MUSIC based on UCA, the high SNR of airborne antennas can heighten the spectrum peak, increase probability of signal and the superiority of the proposed algorithm compared to the experimented ones with a margin error 0.0086%.

REFERENCES

[1] LC Godara. Application of Antenna Arrays to Mobile Communications Part II: Beam-forming and Direction of Arrival Consideration. In: Proceedings of the IEEE.1997, pp. 1195-245.
[2] AK Shauerman and AA Shauerman. Spectral-Based Algorithms of Direction-of-Arrival Estimation for Adaptive Digital Antenna Arrays. In: Proceedings of the 9th international conference and seminar on Micro/Nanotechnologies and Electron Devices, Novosibirsk, Russia. 2010,pp. 251-55,
[3] B Liao and SC Chan. DOA Estimation of Coherent Signals for Uniform Linear Arrays with Mutual Coupling. In: Proceedings of the IEEE International Symposium on Circuits and Systems, Rio de Janeiro, Brazil, pp. 377-80, 2011.
[4] M Jalali, MN Moghaddasi and A Habibzadeh. Comparing accuracy for ML, MUSIC, ROOT-MUSIC and spatially smoothed algorithms for 2 users. In: Proceedings of the IEEE conference Mediterranean on Microwave Symposium (MMS), Tangiers, Morocco, pp. 1-5, 2009
[5] M.A.Ihedrane,S.Bri. *Direction of arrival in two dimensions with matrix pencil method*. Advances in Intelligent Systems and Computing.640.pp.219-228.
[6] J. Capon, R. J. Greenfield and R. J. Kolker, “Multidimensional maximum likelihood processing of alarge aperture seismic array”,Proceedings of the IEEE, 1967,55(2),pp192-211.
[7] A. Paulraj, R. Roy and T. Kailath, “A subspace rotation approach to signal parameter estimation”,Proceedings of the IEEE, 1986, Vol74(7), pp1044-1045.
[8] LC Godara. “Application of Antenna Arrays to Mobile Communications Part II: Beam-forming and Direction of Arrival Consideration,” IEEE Proc. 1997, pp.1195-1245.
[9] C. P. Mathews, M. D. Zoltowski,“Eigen structure techniques for 2-D angle estimation with uniform circular arrays,” IEEE Trans on SP, vol42, 1994, pp. 2395-2407.
[10] Z. Ahmad, I.Ali. Three Decades of Development in DOA Estimation Technology. Indo.J.Elel.Engi.Comp.Scie (IJEECS).Vol12 (8),2014.pp 6297-6312.
[11] M. A. Ihedrane and S.Bri, “2-D DOA estimation using MUSIC algorithm with uniform circular array”,Inter. Collo.Info .Scie & Tech (CiSt). 2016,pp.850- 853,.
[12] El.A. B. Yagoup, Z.Liu and Y. Xu, DOA Estimation by Fourth-Order Cumulants without Source Enumeration and Eigen decomposition.Indo.J.Elel.Engi.Comp.Scie (IJEECS). 2014, 12(6), pp.4237-4242.
[13] S. S. Balabadrapatruni, Performance Evaluation of Direction of Arrival Estimation Using Matlab, Signal & Image Processing. Int. J; vol 3, pp.57-72, 2012.
[14] R. O. Schimd. “Multiple emitter location and signal parameter estimation,” IEEE Trans. Antenna Propaga, Vol. 34, pp. 276–280, 1986.
[15] Panayiotis Loannides, and Constantine A. Balanis, Uniform circula arrays for smart antennas,” IEEE Antennas and Propagation Magazine, vol.47, no.4, pp. 192- 206, 2005.
[16] Mati Wax, and Jacob Sheinvald, “Direction finding of coherent signals via spatial smoothing for uniform circular arrays,” IEEE Trans. Antennas and Propagation, vol.42, no.5, pp.613-620, 1994.
[17] M.A. Ihedrane, S. Bri “Direction of Arrival Estimation using MUSIC, ESPRIT and Maximum-Likelihood Algorithms for Antenna Arrays”, *Wal.J. Sc.Tec* (WJST), Vol.13, pp. 491-502, 2015.
[18] T. AI-Maznaee and H. E. Abd-EI-Raouf. (2009). Design of reconfigurable patch antenna with a switchable V – slot. Progressing In Electromagnetics Research C, 6,145-158.
[19] C.W Jung, Kim, K. Yongin.(2008). Reconfigurable antenna for concurrent operation over cellular and connectivity band. Electronic Letters,44(5),334-335,
[20] Teguh Firmansyah ET all. Bandwidth and Gain Enhancement of MIMO Antenna by Using Ring and Circular Parasitic with Air-Gap Microstrip Structure. TELKOMNIKA (Telecommunication, Computing, Electronics and Control), 2017,15(3), pp. 1155-1163
[21] Y. K. Bekali and M. Essaaidi.(2013)Compact reconfigurable dual frequency microstrip patch antenna for 3G and 4G mobile communication technologies, Microwave and Optical Technology Letters, 55(7).1622-1626.
[22] M.A. Ihedrane, S.Bri and El.F.Adiba. High Resolution Method Using Patch Circular Array, International Journal of Electrical and Computer Engineering (IJECE).Vol.7.no4.2017
[23] W. J. SI, X.Y. LAN and Y. ZOU. Novel high-resolution DOA estimation using subspace projection method, J. Chi. Uni. Pos. Tel,Vol.19, pp.110-16, 2012
[24] T. Varum, J. N. Matos and P. Pinho.Direction of Arrival Estimation Analysis Using a 2D Antenna Array, Proce. Techn, Vol 17, pp.667-624,2013.
[25] B.Sun. MUSIC Based on Uniform Circular Array and Its Direction Finding Efficiency, Inte. J. Sign. Proce. Syst, Vol 1, pp.273-277, 2013.